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Chemiluminescence and the Nomadics Spectrometer Card

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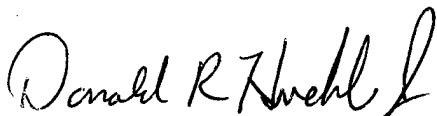
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ABSTRACT

This report presents an experimental study on the potential of employing the Nomadics Spectrometer Card as an analyst of the visible light produced by certain chemical reactions. Following an outline of the experimental procedures, a discussion and analysis section interprets the resulting data and illustrates the value of the Spectrometer Card to chemiluminescent analysis. The final sections summarize the study's findings, describe sources of error, and make recommendations for future uses of the Nomadics Spectrometer Card. All tables and graphs referenced in this report may be found in Appendix A.

OBJECTIVE

Demonstrate the functional capability of the Nomadics Spectrometer Card to analyze chemiluminescent reactions by collecting their visible-light spectra.

INTRODUCTION

The collection of visible-light spectra from chemiluminescent solutions represents an application of the Nomadics Spectrometer Card for which it was not originally intended. Used in conjunction with the Hewlett-Packard Palmtop Computer and Windows CE, the Nomadics Spectrometer Card offers the ability to collect visible-light spectra after an internal light is passed through a solution. This capability traditionally allows for the analysis of semi-transparent solutions by means of the light intensity, absorption, and percent transmission visible-light spectra of solutions, to include concentration determinations. The Spectrometer Card, however, may also be used to collect the spectra of chemiluminescent solutions. To accomplish this, the Nomadics software has been modified to keep the Spectrometer Card's light source off at all times. The sensors of the Spectrometer Card can conveniently detect the visible light emitted by a chemiluminescent solution. Most of the Spectrometer Card's features also apply to the analysis of chemiluminescent reactions. This allows for the accurate recording of the wavelengths and intensities of chemiluminescence across the visible-light spectrum. The following experiment validates such a concept.

EXPERIMENTAL PROCEDURES

To test the practicality of using the Nomadics Spectrometer Card to record chemiluminescence, a strong and readily available chemiluminescent was needed. Convenient test candidates included Cyalume® glowsticks produced by the Omniglow Corporation and Rod-n-Bobb's Beacon™ Refills. Both green and blue Cyalume solutions were obtained, while the Beacon Refills were only available in green. All three chemiluminescent solutions provided some variability in the experiment. For all trials, the Spectrometer Card sampled with a 2000 millisecond integration time and averaged two scans.

The blue Cyalume solution was tested first. The glowstick was activated by snapping the internal vial of hydrogen peroxide and shaking the solution. The top of the stick was then cut off and the chemiluminescent solution poured into a beaker. Enough chemiluminescent fluid was then transferred to fill a one-centimeter cuvette. The first three trials were run immediately in a completely dark room, including the covering of the palmtop computer's display screen with solid black plastic. A background was taken with a blank cuvette, followed by the first sampling of the blue Cyalume (Blue1). The resulting spectrum was saved, and a remeasurement (Blue2) of the sample was performed. The background of the blank cuvette was then retaken and an additional sampling (Blue3) of the blue Cyalume performed to ensure consistency of results. One hour later, the blue Cyalume was sampled under normal ambient (fluorescent) lighting (Blue5, Blue6, and Blue7) and again in the dark room (Blue9 and Blue10). Multiple trials were performed to ensure consistency of results.

Experimentation with the Green Cyalume was performed in the same manner as the Blue Cyalume. The initial eight trials (Green1–Green8) were performed immediately upon activation of the chemiluminescent, under variable lighting conditions (i.e. under fluorescent lighting and in a dark room). One sample was then taken every hour afterwards (Green10–Green15) for six hours, under ambient lighting conditions, to demonstrate the ability of the Nomadics Spectrometer Card to sense variable chemiluminescent intensities.

The Beacon Refill solution was the last to be tested. Experimental procedures emulated the previous two. In this case, however, trials were only run in the ambient light and only a small volume of solution could be obtained from the Beacon Refill. This volume only filled the very bottom of the cuvette, not rising to the level of the spectrometer's sensor. As a result, the cuvette with the chemiluminescent solution was sampled at variable positions in the cuvette-holder to gain the best spectrum (Beacon1–Beacon5).

Finally, blank cuvettes were used for the background and sample to collect example spectra of noise under ambient lighting and in the dark room.

RESULTS

All spectra's data were saved to the palmtop computer's memory. A summary sheet, including names, times, maximum intensities and corresponding wavelengths, and brief descriptions of each trial is found in the attachments as "Selected Data For Chemiluminescent Solution Trials." Included in the attachments are graphs of the "Blue Cyalume Spectra," the "Green Cyalume Spectra Measured Under Various Lighting Conditions," the "Green Cyalume Spectra Measured Over Time," and the "Green Beacon Filler."

The chart below summarizes the results of noise testing with the Spectrometer Card and blank cuvettes.

Trial	Number of Peaks Over a 25 count Intensity	Locations of Peaks (nm)	All Peaks Under this Intensity (counts)
Ambient1	8	455, 500, 510, 540, 560, 600, 610, 640	45
Ambient2	4	510, 535, 675, 625	45
DarkRoom1	7	455, 460, 505, 550, 560, 600, 645	40
DarkRoom2	5	455, 505, 550, 595, 645	60

DISCUSSION AND ANALYSIS

From the "Blue Cyalume Spectra" and "Green Cyalume Spectra Measured Under Various Lighting Conditions" graphs, it can be concluded that there is no difference in results when performing tests under ambient lighting versus a dark room. The Blue5–Blue10 trials all yielded the same spectra, as well as the Green1–Green8 spectra. The intensity of successive trials decreases, since the chemiluminescent solution was slowly "burning out". Random noise accounts for the slight variability in the shapes of the curves. Noise, however, never disrupted trials in controlled environments, considering the measured noise remained under 60 counts of intensity in experimentation (see table in RESULTS section). While noise appeared to be consistent at certain wavelengths, it is still practical to assume the effects of noise may be reduced as the number of scans averaged for each trial increases, though this procedure was not attempted since noise was already insignificant for our experimentation purposes.

Experimentation with the green Cyalume demonstrated the Nomadics Spectrometer Card's capability of accurately measuring variable intensities of chemiluminescence. The "Green Cyalume Spectra Measured Over Time" graph illustrates the spectra recorded by the Spectrometer Card over a period of six hours. As the Cyalume died out, the spectrometer produced visible-light spectra that paralleled the decreasing intensities. When the maximum intensities of the green Cyalume were plotted over time in the graph entitled "Green Cyalume Peak Intensities over Time," a near-exponential model was created.

Testing with the green Beacon Filler served to exemplify the use of the Nomadics Spectrometer Card to distinguish between different chemiluminescent reactions. Before proceeding, though, a strong signal had to be obtained from the green Beacon Filler. The refills contained barely enough fluid to cover the bottom of the cuvette. For this reason, trials varied the position of the cuvette in the spectrometer's cuvette-holder in order to gain the strongest spectrum. When the cuvette was lowered 1/2-way down into the cuvette-holder, the beacon filler sat at the same level as the spectrometer's 50 μ m optical fiber and resulted in the strongest spectrum. The "Green Beacon Filler" graph shows the five trials. With a Beacon Filler spectrum obtained, a comparison can be made between the three different chemiluminescent solutions (i.e. blue Cyalume, green Cyalume, and green Beacon Filler). The graphs of Blue1, Green1, and Beacon2 are brought together in "Cyalume Spectra Comparison," and demonstrate the means by which the Nomadics Spectrometer Card can be employed to distinguish chemiluminescent solutions. The graphs obviously allow for the determination of each solution's color, with Green1 peaking between 520 and 550 nanometers (green), Blue1 peaking between 450 and 480 nanometers (blue), and Beacon2 peaking between 530 and 560 nanometers (green). Notice the Beacon Filler registers as a slightly lighter green than the green Cyalume, which parallels personal observations made in the laboratory. The graph also shows that each chemiluminescent solution possesses a different shaped curve. Even when the colors are nearly identical (i.e. Green1 and Beacon2), and even if their intensities were exactly the same, the solutions produce completely different shaped curves.

CONCLUSIONS

Tests under variable lighting conditions show the Nomadics Spectrometer Card is capable of compensating for ambient light and only obtaining the spectrum of the desired chemiluminescent solution. Whether in a dark room or under fluorescent lighting, the spectrometer obtains the same readings.

The Nomadics Spectrometer Card accurately differentiates between the visible-light intensities of chemiluminescent solutions. This capability not only allows differentiation of chemiluminescent solutions, but the monitoring and/or modeling of the rate at which chemiluminescent reactions die out.

Chemiluminescent reactions may be distinguished and/or identified by the visible-light spectra obtained with the Nomadics Spectrometer Card. Unique chemiluminescent solutions yield uniquely shaped curves.

Noise has remained insignificant in this experiment, and has not drastically affected results. Two scans were averaged in each of this experiment's trials to help counter the effects of noise, though more precision-oriented experimentation may wish to substantially increase the number of averaged scans to further reduce noise. Lighting in this experiment, however, remained consistent (i.e. dark or fluorescent) and toleration for error was average for laboratory purposes. Additional methods for reducing noise may be considered for harsh environments or more precise experimentation.

Overall, the Nomadics Spectrometer Card, with its software modified so that its internal light source remains off, offers a convenient means to analyze chemiluminescent solutions. Though experimentation is quick and easy, the system produces precise results. Studies of chemiluminescence should consider the Nomadics Spectrometer Card as a convenient and dependable tool.

RECOMMENDATIONS AND SOURCES OF ERROR

Though the Beacon Filler represented the problem of only having a small volume for sampling, the experimental methods outlined in this report do not represent the only means. Alternative solutions to varying the cuvette's position in order to obtain the best spectrum include acquiring more of the chemiluminescent solution or diluting the solution with a capable solvent.

Experimental data could not be directly communicated from the palmtop computer to any other system, due to a missing connection cable. As a result, all data was read from the palmtop computer and manually entered into a personal computer. In the interest of time, only data points for every fifth nanometer of wavelength between 450 and 650 nanometers were transferred to the personal computer for data analysis. This represents a decrease in graphical resolution from one nanometer on the palmtop computer to five nanometers in this report.

Minor anomalies occurred in the saving of data files collected by the Nomadics Spectrometer Card. Once a data file was saved and reopened, the saved spectrum on a few occasions was shifted from the original spectrum displayed on the screen by the "No Light Spectrometer" software immediately after collection. The shapes of spectra curves were never affected, but were entirely shifted up to fifteen nanometers. It was assumed that the spectra displays produced from the saved files were correct, since they were consistent with other error-free files. If the assumption is correct, then the initial display and quantitative readings of spectra by the "No Light Spectrometer" software are subject to being skewed on occasion.

WORKS CONSULTED

None

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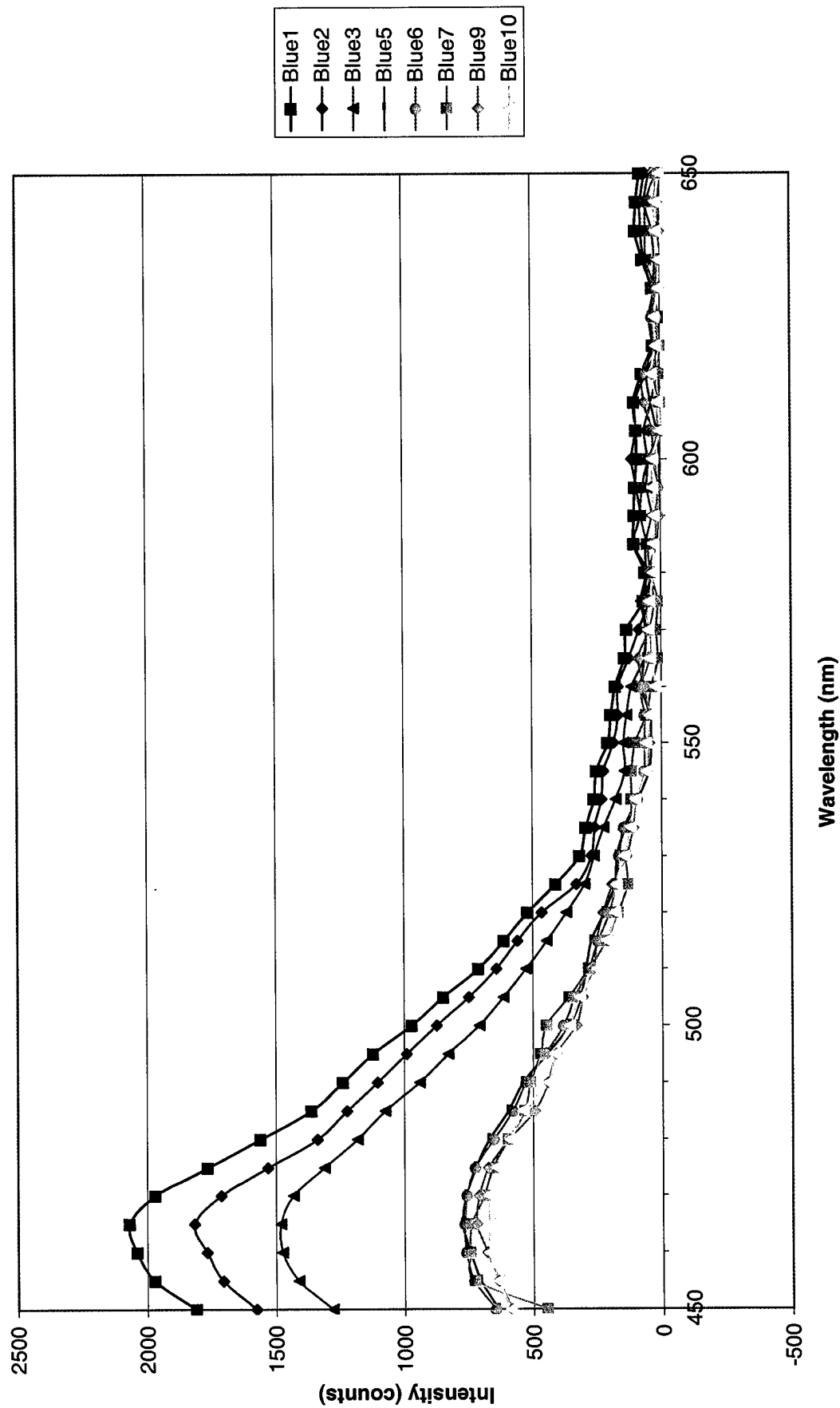
All ideas, research, and experimentation were achieved cooperatively by Dr. Howard Mayfield, Mr. Bruce Nielsen, and Cadet Anthony DeGregoria, AFRL/MLQ.

Appendix A

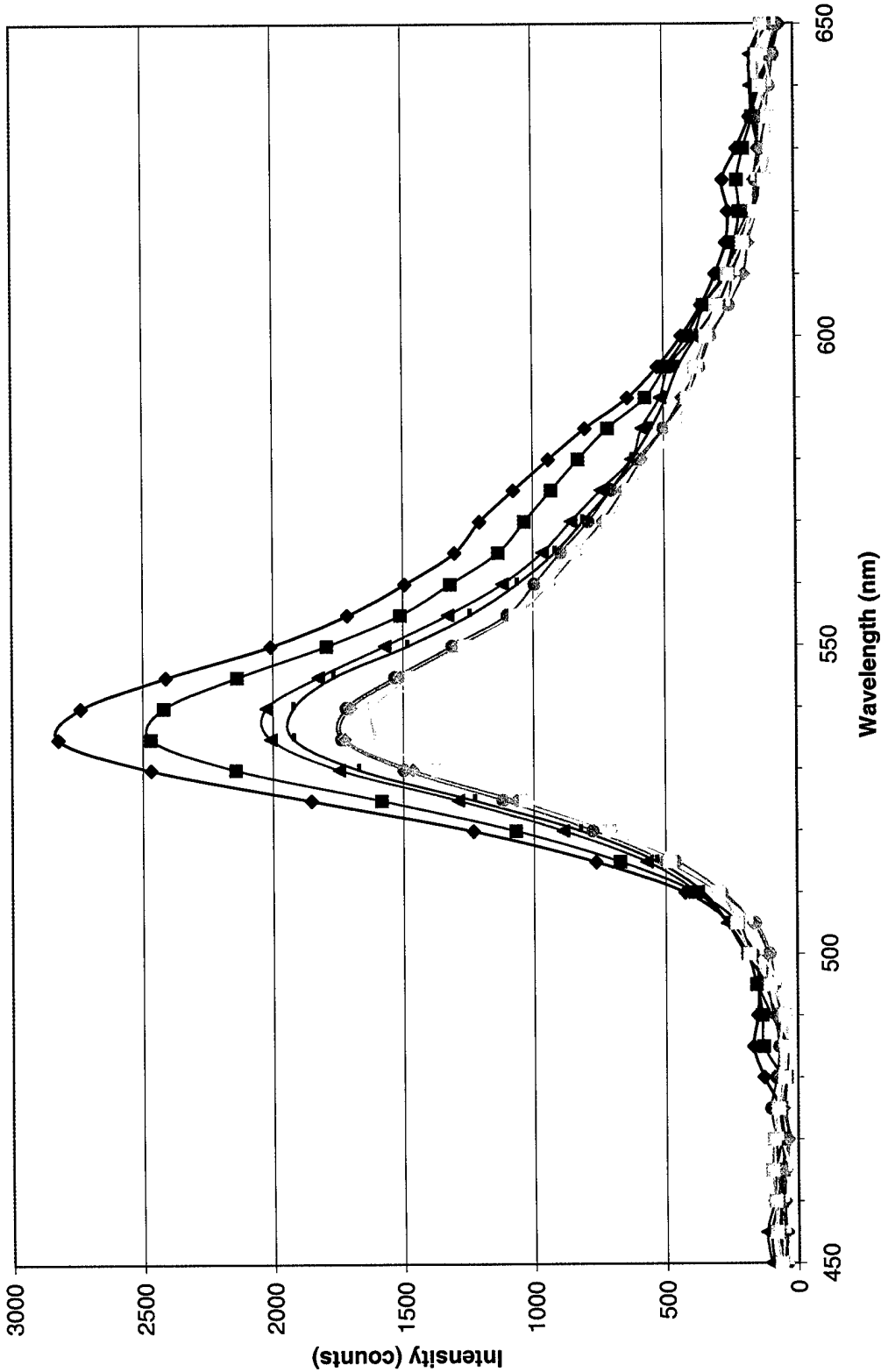
SELECTED DATA FOR CHEMILUMINESCENT SOLUTION TRIALS

Trial	Date	Time	Time from Start (minutes)	Wavelength of Max Intensity (nm)	Max Intensity (counts)	Description
Blue1	6/4/99	10:09	0	465	2068	background and blue Cyalume measured in dark room
Blue2	6/4/99	10:12	3	465	1816	blue Cyalume remeasured
Blue3	6/4/99	10:15	6	462	1500	new background taken and blue Cyalume remeasured
Blue5	6/4/99	11:06	57	465	773	background and blue Cyalume measured in ambient light
Blue6	6/4/99	11:07	58	463	767	blue Cyalume remeasured
Blue7	6/4/99	11:09	60	459	748	new background taken and blue Cyalume remeasured
Blue9	6/4/99	11:13	64	468	724	background and blue Cyalume measured in dark room
Blue10	6/4/99	11:14	65	468	684	blue Cyalume remeasured
Green1	6/8/99	8:21	0	536	2846	background and green Cyalume measured in ambient light
Green2	6/8/99	8:23	2	537	2502	green Cyalume remeasured
Green3	6/8/99	8:26	5	537	2044	background and green Cyalume measured in dark room
Green4	6/8/99	8:27	6	537	1954	green Cyalume remeasured
Green5	6/8/99	8:31	10	537	1760	background and green Cyalume measured in ambient light
Green6	6/8/99	8:32	11	537	1746	green Cyalume remeasured
Green7	6/8/99	8:35	14	537	1628	background and green Cyalume measured in dark room
Green8	6/8/99	8:36	15	537	1605	green Cyalume remeasured
Green10	6/8/99	9:30	69	537	1026	background and green Cyalume measured in ambient light
Green11	6/8/99	10:33	132	539	684	background and green Cyalume remeasured
Green12	6/8/99	11:32	191	542	484	background and green Cyalume remeasured
Green13	6/8/99	12:48	267	534	333	background and green Cyalume remeasured
Green14	6/8/99	13:38	317	539	263	background and green Cyalume remeasured
Green15	6/8/99	14:31	370	536	205	background and green Cyalume remeasured
Beacon1	6/8/99	8:43	0	556	628	green filler measured in ambient light (¾-way down position)
Beacon2	6/8/99	8:44	1	554	1119	green filler remeasured (½-way down position)
Beacon3	6/8/99	8:45	2	551	1014	green filler remeasured (½-way down position)
Beacon4	6/8/99	8:46	3	551	869	green filler remeasured (¼-way down position)
Beacon5	6/8/99	8:47	4	534	458	green filler remeasured (all-the-way down position)

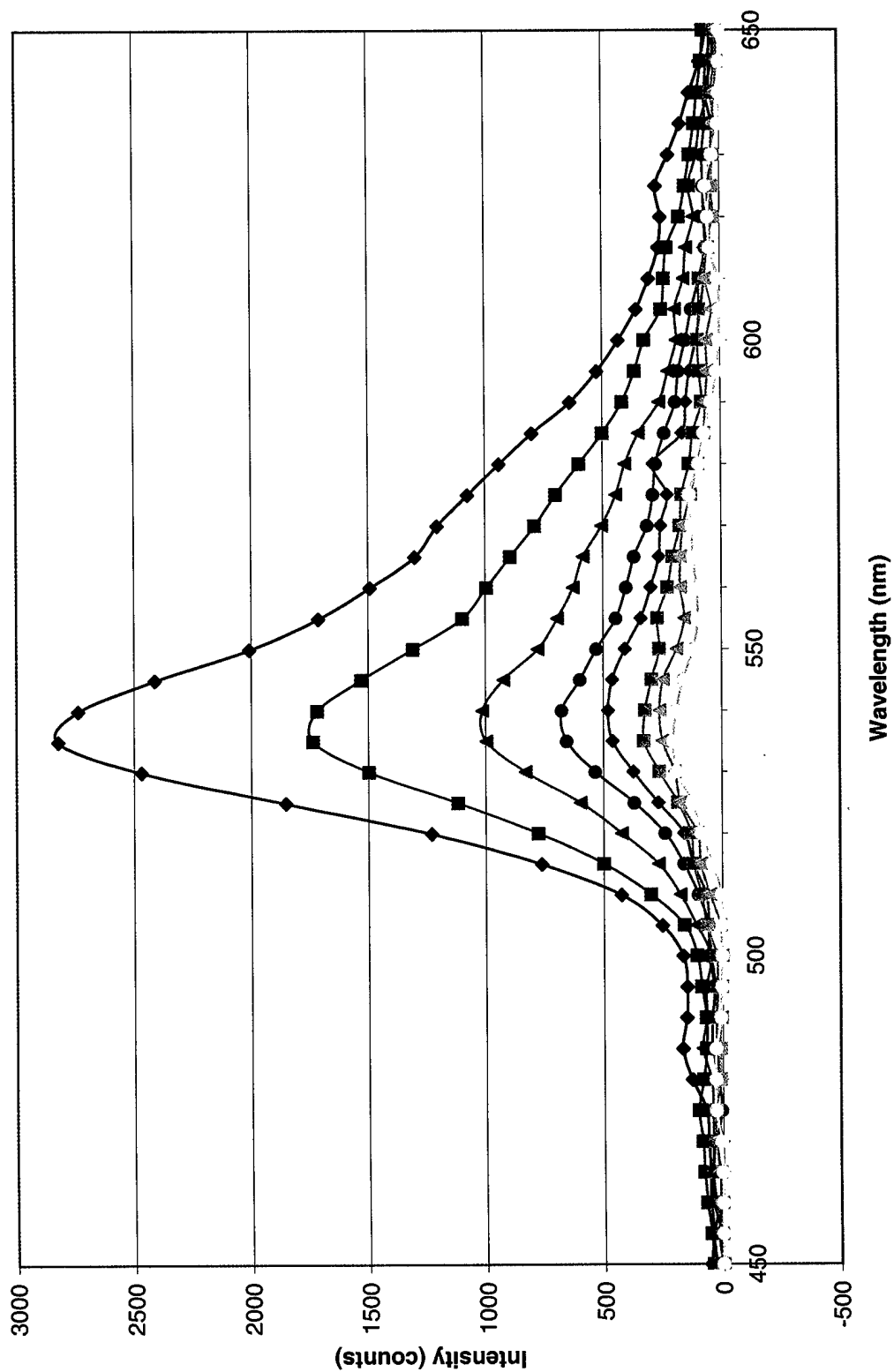
Blue Cyalume Spectra



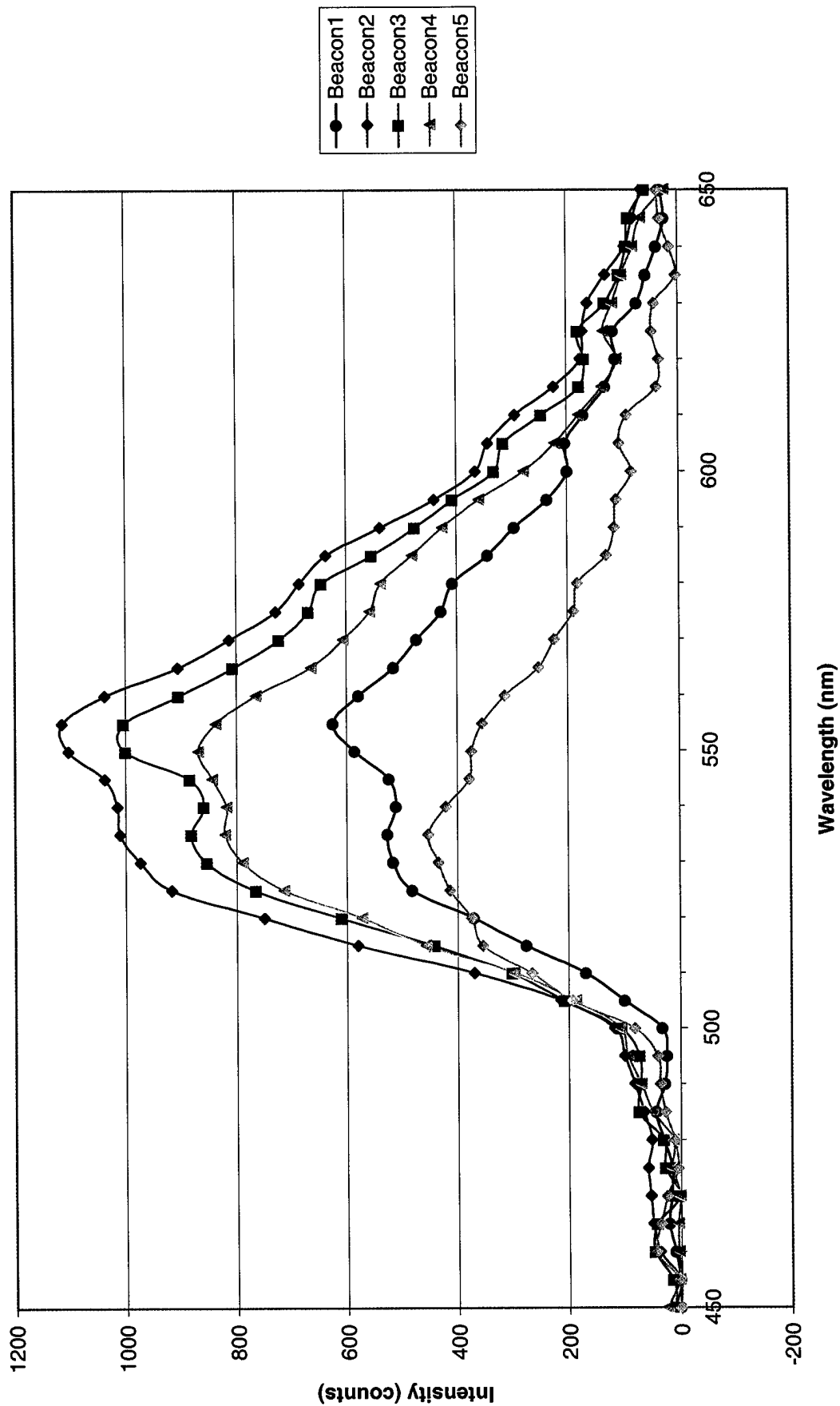
Green Cyalume Spectra



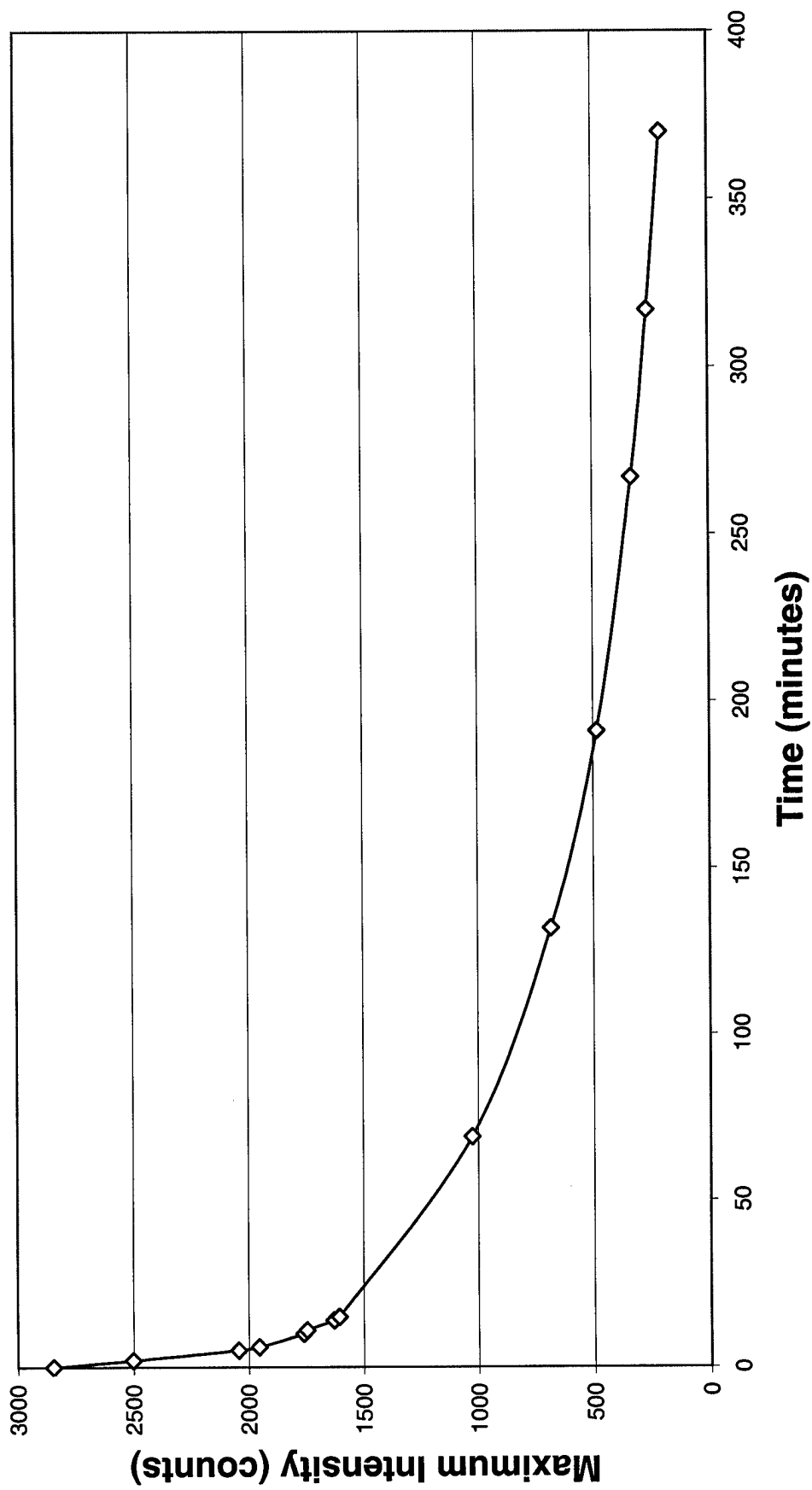
Green Cyalume Spectra
Measured Over Time



Green Beacon Filler



Green Cyalume Peak Intensities over Time



Cyalume Spectra Comparison

